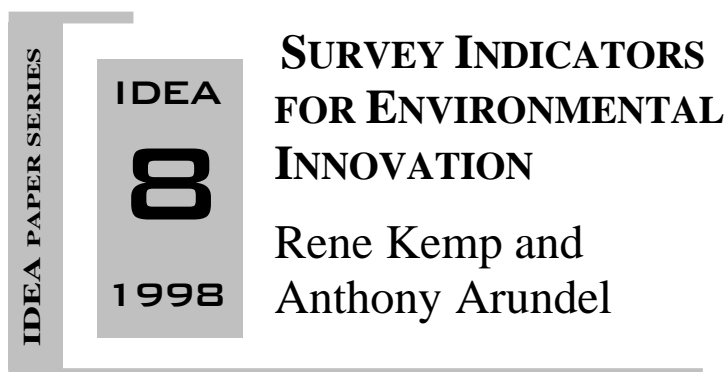


IDEA paper



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IDEA

This report is from Sub-Project 2.2, 'Indicators on the importance of environmental goals', of the IDEA (Indicators and Data for European Analysis) Project. IDEA is Project No. PL951005 under the Targeted Socio-Economic Research Programme, Area 1 (Evaluation of Science and Technology Policy Options in Europe), Theme 1.3: *Methodologies, Tools and Approaches Relevant for the Preparation, Monitoring and Evaluation of Science and Technology Policies*.

An overview of the project as a whole, covering objectives, work programme, and results, including downloadable reports, can be found on the IDEA Web-site:

<http://www.sol.no/step/IDEA/>

ABSTRACT

This report sets out to describe indicators on environmental technological innovation and their usefulness for environment-related STI policy and innovation study. Environmental technological innovations consist of new or modified processes, techniques, systems and products that help to reduce environmental damage. This is a new area for indicator research. In this report we will examine how environmental technological innovation output and processes may be measured by indicators, and how indicator research can assist public policy makers in furthering the development, adoption and use of environmental innovations.

The structure is as follows. Section 1 provides a taxonomy of environmental technological innovation. This is followed in section 2 by a discussion of indicators on environmental technological innovation and problems of collecting and interpreting the indicators. This includes a discussion of two studies of environmental innovation: that of Green et al. (1994) for the UK and that of Malaman (1996) for Italy, and is followed by a more general discussion of problems in studying environmental innovation and of analytical challenges for environmental innovation research. Lessons for environmental innovation research are discussed in section 3. The final section develops a design for a pilot study on environmental innovation, in the form of a prototype questionnaire and survey format.

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INTRODUCTION

Two main challenges face the development of indicators for environmental innovation. The first challenge is that *the environment is virtually everywhere*. Every aspect of manufacturing can affect the environment: the choice of materials, the characteristics of the production process, and the characteristics of manufactured products. In addition, environmental effects can occur not only during the production phase but during the entire life-time of a product.

The second challenge is that many innovations that are beneficial to the environment are not readily recognisable as such. Environmental improvements can occur as a side-effect of process innovations to reduce costs or enhance product quality. Furthermore, products that can be environmentally benign, such as bicycles, may not be viewed as environmental products by their manufacturers.

This chapter examines how environmental innovation, particularly technical innovation, can be measured. The focus is on developing indicators that can assist public policy makers to implement programmes that can encourage the development, adoption and use of environmental innovations. In addition, the results of such indicators will be of value to firms as a benchmark for environmental behaviour in their industry.

What is environmental innovation?

Environmental innovation consists of new or modified processes, techniques, systems and products to avoid or reduce environmental harms. They can concern either technical or organisational innovation. The latter include changes in the organisational structure, routines and practices of a company. As noted elsewhere in the IDEA project, survey techniques are not suited to measuring most types of organisational innovation. These are better studied through semi-structured interview techniques or case studies. However, some types of organisational innovations could be an essential prerequisite to technical environmental innovation. For this reason, a few relevant indicators of organisational innovation are discussed below.

Technical environmental innovation

There are two main methods of classifying technical environmental innovations. The first method is based on the motivations or reasons for their development, while the second is based on the purpose of the innovation, or how it is used¹.

Environmental innovations can be expressly developed to reduce environmental harm or their environmental benefits can be a side-effect of other goals. An example of the first class is flue-stack scrubbers to remove sulfur dioxide. This type of innovation is relatively simple to identify as an environmental innovation. The second class is more problematic. This consists of innovations that are primarily developed for non-environmental reasons, but which have beneficial environmental effects. An example is a photovoltaic energy cell for calculators. These were developed because they permitted thinner calculators that never ran out of power, but they also had the environmental benefit of reducing the use of batteries, most of which are thrown away after use. Many clean consumer products belong to this second class. The existence of these two classes of environmental innovations requires two sets of indicators: one for innovations that are developed in response to regulations (compliance innovations), and another that can identify the environmental component of other types of innovations.

There are two main categories of the purpose or use of an environmental innovation. The first consists of end-of-pipe applications where a technology is added to an existing production system. The second consists of clean technologies that reduce the production of pollutants or inputs of energy and materials. These two broad categories can be further subdivided into six types of environmental innovation².

1. *Pollution control technologies* that prevent the direct release of environmentally hazardous emissions into the air, surface water or soil.
2. *Waste management*: handling, treatment, and disposal of waste; both on-site by the producer

¹ Another method of classifying technical environmental innovations is along a continuum ranging from minor incremental innovations to radical innovations. An example of a radical environmental innovation is the upflow fluidized bed reactor for anaerobe wastewater treatment. This system was originally used to deal with organic pollution. Incremental innovations on this system have adapted it for use in treating other pollutants, including metals.

² Based on Skea (1995, p.390) and Tweede Kamer (1982, p.14). Similar definitions can be found in OECD (1985), Cramer and Schot (1989), and Ashford (1993). Monitoring and assessment technologies that are used to monitor the condition of the environment, releases of pollutants, and identification of pollutants are sometimes also included among environmental technologies (Skea, 1995).

of the waste and off-site by waste management firms³.

3. *Clean technology*: process-integrated changes in production technology that reduce the amount of pollutants and waste material that is generated during production.
4. *Recycling*: waste minimisation through the re-use of materials recovered from waste streams.
5. *Clean products*: products that give rise to low levels of environmental impact through the entire life cycle of design, production, use and disposal. Examples are low-solvent paints and bicycles.
6. *Clean-up technology*: remediation technologies such as air purifiers, land farming and bioremediation, which uses plant species to remove toxic materials from contaminated soil.

Pollution control technologies are often referred to as end-of-pipe (or add-on) technologies because they are typically added to existing production equipment. They constituted the common response of industry to government pollution control policies in the 1970s and 1980s. They still account for the largest share of investment on environmental technologies, with their share estimated at 80 per cent in Belgium, 82 per cent in Western Germany and 87 per cent in France in 1987.⁴ Since the late 1980s, when pollution *prevention* rather than control became the focus of government policies, technology responses shifted away from pollution control technologies to cleaner production processes and recycling that prevent pollution or reuse waste material.

Another recent development is that of cleaner products, which are less environmentally harmful over their entire life-cycle, rather than just during their production phase or at the point of use. They include 'green' or eco-products such as compact phosphate-free detergents or energy-efficient washing machines, plus products that are inherently environmentally benign such as bicycles and insulation material.

These six types of environmental technologies can be placed into a scheme, as shown in Table 1, that classifies each technology on the basis of its motivation for development and its main purpose or application. Table 1 shows that three categories of environmental innovation; clean technology, recycling, and cleaner products, can be developed both in response to regulation or

³ 'Waste management' is often used as a general term for waste reduction and recycling. Waste reduction covers a wide range of measures: technological changes in production processes (retrofitting and cleaner processes), input material changes, product changes and good operating practice (also known as good housekeeping) (Clift and Longley, 1996).

⁴ Recherche Développement International, quoted in Skea, 1995.

for other reasons. Recycling technologies can be used both in an end-of-pipe context and as a clean technology.

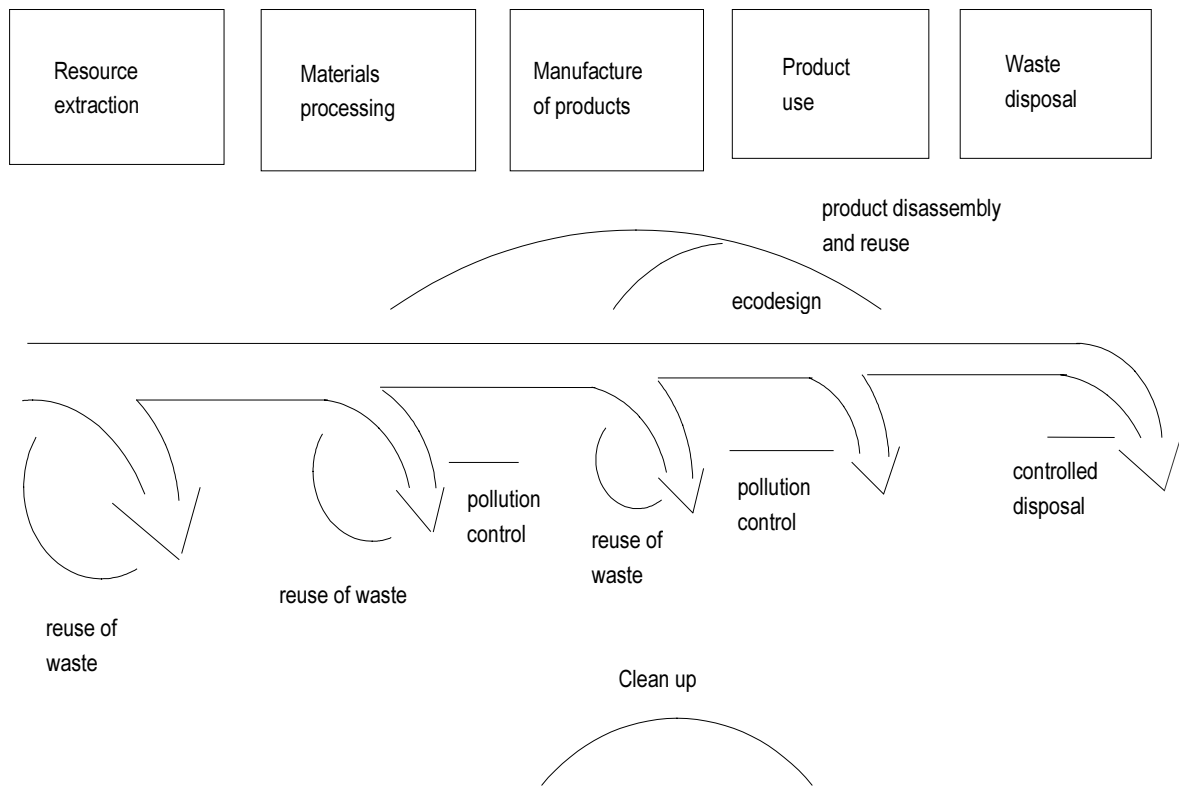
Table 1: Typology of environmental innovation

Developed in response to:	Method of use	
	<i>End-of-pipe</i>	<i>Clean technology</i>
Regulation	Pollution control technologies	Cleaner technology
	Recycling	Recycling
	Waste management	Waste management
	clean-up technology	Clean products
Other goals	<i>None</i>	Cleaner technology
		Recycling
		Clean products

An overview of environmental technologies in the production-waste system is given in Figure 1. It shows the different routes for reducing the use of resources, for generating less waste, and for reducing pollutant emissions. The different options can be organised into a hierarchy, ranging from the best to the least effective: waste elimination, source reduction, recycling (internal and external), treatment and disposal (Clift and Longley, 1996; Hirschhorn et al., 1993). The hierarchy, which is referred to as the waste ladder, is based on a mixture of environmental and economic considerations⁵.

⁵ From an *economic welfare* perspective, which option is best depends on the economic value of environmental gains compared to the costs of achieving such gains. The best option are those where the monetary value of the benefits exceeds the costs of achieving them. In an *environmental* perspective one looks only at environmental benefits, which may be varied, creating a problem of comparing different types of environmental benefits (for example a reduction in SO₂ against a reduction in NO_x). It should be noted that the two perspectives are not necessarily in conflict: in both perspectives pollution prevention is usually preferred over pollution treatment and remediation. The reason for this is that prevention, in most cases, is less expensive than treatment and remediation.

Figure 1: Environmental technologies in the production waste chain



Organisational environmental innovation

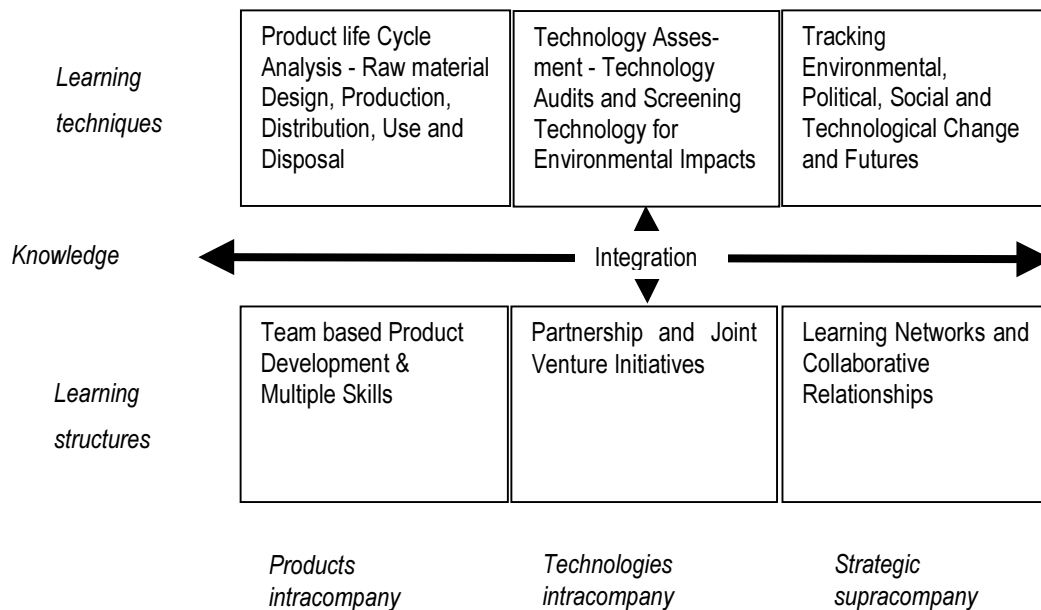
Effective linkages between organisational and technological innovation are crucial to the successful development and application of many different types of technologies. However, a substantial body of research argues that the links between organisational change and environmental innovation go further than that required for other types of innovation. This is due to the crucial differences in the reasons why firms undertake innovation. Under most conditions, the incentive to innovate is based on expectations of a higher profit level, or at the minimum maintaining a satisfactory return on investment. In contrast, the motivation to undertake environmental innovation is considerably more complex and it may be undertaken even when it is not profitable. It can be driven by regulation, competitive factors such as the desire to maintain good relations with customers, or as a result of a social awareness of the need for clean production.

Much of the literature emphasises the need for firms to adopt an environmental consciousness or ‘ethos’, such that their business decisions automatically include environmental concerns. This requires changes to the firms organisational practice. For example, Roome (1994) argues that a company must reshape its organisational relationships as well as employ new practices that can introduce environmental concerns into its existing innovative activities. Lenox and Ehrenfeld (1997) refer to a firm’s ‘environmental design capability’, or the ability to incorporate environmental concerns into product development. This capability depends on both the integration of diverse knowledge resources and on the firm’s level of commitment to environmental innovation. In their study on green product development, they found that resources are insufficient if they are not linked with design teams and embedded in interpretative structures *which value and understand* environmental information (Lenox and Ehrenfeld, 1997: 195).

Several different types of organisational innovations are relevant to environmental goals. The simplest consists of a mission statement in support of sustainable development, which does not necessarily guarantee concrete actions to meet this goal. More concrete environmental innovations include environmental training programmes, green product design programmes, or programmes to make an existing plant or process more environmentally benign. Other organisational innovations include the introduction of environmental learning techniques (such as Product Life Cycle Analysis), the allotment of tasks and responsibilities, environmental managerial and auditing systems, the establishment of communication channels to respond to environmental problems (Shrivastava, 1995), the creation of management teams to deal with environmental issues, and the establishment of interorganisational networks and partnerships.

Firms may also need to incorporate continuous learning mechanisms to learn about the environmental impact of the firm’s products and processes and to continually monitor regulatory, technical and social developments. Apart from these techniques for learning, Roome (1994) also stresses the importance of learning *structures* to integrate environmental knowledge into R&D processes. These learning structures consist of intra-organisational teams, partnerships with other companies, and learning networks with stakeholders. Roome provides a conceptual model of six essential elements for R&D management in an environmentally aware company. This model is depicted in Figure 2.

Figure 2: Building environmental complexity into R&D Management (source: Roome 1994:78)



Strategies for environmental innovation

Most research on the environmental strategies of firms focus on organisational issues rather than on R&D and innovation strategies (Winn and Roome, 1993; Miles and Green, 1996). However, two recent studies develop a model of firm strategy that incorporates innovation.

Green and McMeekin (1995) develop a six-stage continuum model that traces the development of a firm's policies towards environmental issues. The model is depicted in Table 2. The first stage represents a company with a resistant attitude to environmental pressures. This response is what Roome (1992) calls non-compliance and Steger (1993) an indifferent strategy. At stage 2 the company takes a reactive approach to perceived environmental threats. R&D concentrates on minor changes to products and processes and is essentially a defensive strategy.

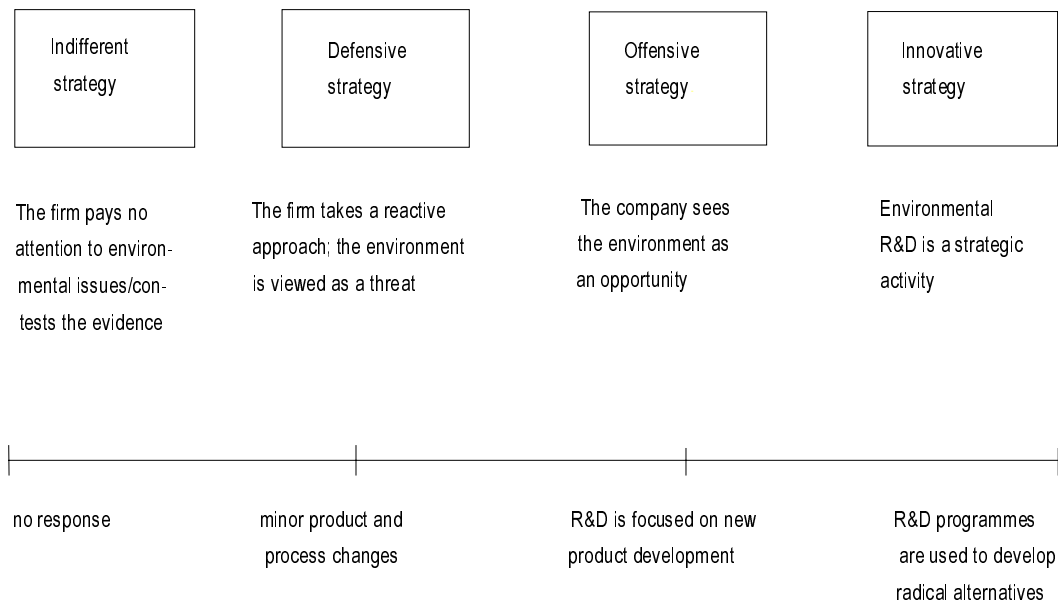
At stage 3 the company begins to view the environment as an opportunity rather than a threat and it starts to focus R&D on new product development, though without major technological change. At stage 4 the company goes one step further by focusing its R&D on new types of processes and/or products that will give it some medium-term competitive advantage. Stages 3 and 4 represents an offensive (Steger, 1993) or compliance-plus strategy (Roome, 1992).

A company at stage 5 seeks new technological directions, for example by developing radical alternatives that can be sold in new markets. At stage 6 the company seeks cleaner technological regimes through which it can offer new products and/or alternative technologies that create new industrial sectors and product systems. Stages 5 and 6 represent an innovative strategy (Steger, 1993). The last strategy could also be necessary to fulfil sustainable economic development.

Figure 3 gives a simplified version of the continuum model of technological response to environmental pressures, using Steger's taxonomy. Aside from the optimistic bias in favour of an environmental ethos, the merit of both of these models is that they link environmental strategies to R&D and technology. These strategic aspects are important because a firm's strategy determines the rigour and nature of its innovative activities. For example, companies that take a defensive attitude are unlikely to develop innovative solutions, although they could adopt innovations developed outside of the firm. Furthermore, an environmental ethos is not always needed to reach the highest stage. A firm could adopt an innovative strategy because it is in the market to develop environmental process innovations that are then sold to other firms.

Research on environmental innovation, therefore, needs to consider the strategic aspects of environmental management, together with environmental organisational aspects at the operational level: the use of environmental audits, eco-teams, etc. There is clearly an interactive relationship between innovation, organisation and strategy.

Figure 3: Technological responses to green pressures



REVIEW OF EXISTING INDICATORS OF ENVIRONMENTAL INNOVATION

Surprisingly, given the widespread interest in the environment and in regulatory and economic instruments to encourage environmental innovation, there are very few available indicators of environmental innovation. Most innovation surveys have only included one or two questions on environmental innovation. The few existing surveys that have focused on environmental innovation are largely drawn from the management literature and examine the reasons why firms introduce environmental innovations and their organisational response to environmental issues. Most of our knowledge of environmental innovation comes from the extensive case study literature and from surveys that focus on management, organisation, and strategies. The disadvantage of case studies is that the results are often based on only a few firms, which raises problems about generalisability and selection bias, while the management literature does not look

directly at technical innovation⁶.

Traditional indicators

The most widespread measure of environmental innovation is the amount spent by firms on capital equipment to reduce pollution. These are termed Pollution Abatement Costs and Expenditures (PACE) and have been collected on an annual basis in the United States, France and Germany and on an irregular basis in the Netherlands, the UK, and Canada (Olewiler, 1994). The PACE estimates are probably not exactly comparable between countries. In the United States, the Commerce Department survey asks respondents to estimate their *additional* capital expenditures due to environmental regulations (Jaffe *et al*, 1995). The question is partly hypothetical since these additional expenditures can only be estimated on the basis of no regulation. The PACE estimates also have several other drawbacks. They do not include investment in R&D or other inventive activities, and they are more likely to reflect end-of-pipe investments than investment in cleaner technology or technologies that reflect non-environmental goals but which have environmental benefits.

Despite these disadvantages, PACE data have been useful for estimating the effect of regulation on output and competitiveness. The data also indicate that pollution abatement costs are much higher in several resource sectors such as paper and allied products than for advanced manufacturing such as electronic equipment and machinery (Jaffe *et al*, 1995).

The US department of Commerce has also collected data on cost offsets. These are savings that can result from investment in pollution abatement equipment. For example, investment in a pollution control system to capture heavy metals, such as cadmium, that were previously discharged into the environment can partly be recouped by selling or reusing the heavy metals. The ratio of the offset to the investment in pollution abatement could form a strong incentive to develop environmental innovations and influence the type of innovation that is implemented. This ratio has also been subject to strenuous debate, with Palmer *et al* (1995) using the department of Commerce offset data to show that the offset benefits amount to less than 2% of US expenditures on pollution abatement, while Porter and van der Linde (1995) have argued, on

⁶ Examples of relevant case studies include Dupuy (1997), Clarke & Roome (1995), Groenewegen and Vergragt (1991), and Lenox and Ehrenfeld (1997).

the basis of case studies, that offsets, combined with properly-formulated regulatory policies, could approximate or exceed the costs of pollution control. The latter is commonly referred to as a 'win-win' scenario. The results of this debate has important implications for the formulation of environmental regulation (Howes *et al*, 1997).

Survey Indicators of Environmental Innovation

The family of innovation surveys that have been inspired by the Oslo Manual (OECD, 1992) only include a few questions of relevance to environmental innovation. These are summarised in Table 2. The questions focus exclusively on two issues: the importance to the firm's innovative goals of reducing inputs and the effect of regulations as a barrier to innovation. The former is of immediate significance to environmental innovation. The format of the question avoids the motivational issue, since innovation to reduce materials use could be in response to regulation or simply to reduce production costs. The questions on regulation as a barrier to innovation are much less relevant to environmental regulation because they rarely, with the exception of the MERIT-PACE study, focus on environmental regulation alone.

Specialised environmental innovation surveys

Only a few surveys have focused on environmental innovation⁷. One example which is discussed here is the 1993 survey by Green *et al* (1994). The survey was sent to a sample of 800 firms that had expressed an interest in the UK department of Trade and Industry (DTI) Environmental Technology Innovation Scheme (ETIS). Under the scheme, companies could receive a subsidy for industrial R&D that might improve environmental standards. Responses were received from 169 firms, for a relatively low response rate of 21.1%.

The survey questions are summarised in Table 3. The first question asks about the motivations for developing environmental innovations⁸ while the second asks about several broad categories

⁷ Williams *et al* (1993) and Garrod and Chadwick (1995) conducted small-scale interview surveys. A larger survey of 592 German firms by Steger (1993) examines the importance of several motives for introducing environmental protection measures, but it does not explore the firm's own innovative activities. Other surveys, such as by Doyle (1992) and by Ijst *et al* (1988) only survey environmental equipment manufacturers and are of less interest here.

⁸ Existing UK/EC regulations show up as the most significant factor, both for product and process innovations. This result is confirmed by two other UK studies by Williams *et al*. (1993) and Garrod and Chadwick (1995), whereas a study by Steger (1993) for Germany finds that social responsibility is the most significant factor, closely followed by environmental regulation.

of potential applications of environmental redesign. The third question is related to pollution abatement costs, except that the version used by Green *et al* covers all environmental activities and not just pollution abatement. The fourth question is limited to a specific product and process innovation that is selected by the firm. The focus of the sub-questions is on the inputs and information sources required to develop these innovations. These questions are similar to the CIS questions on the inputs into general innovative activities.

Table 2: Environmental innovation indicators included in the family of innovation surveys based on the Oslo Manual

Survey	Question	Measurement scale
CIS - 1 (1993)	Importance to the firm of developing and introducing innovations to lower production costs by: 1. reducing materials consumption 2. reducing energy consumption	five-point scale ranging from insignificant to crucial
“	Importance to the firm of developing and introducing innovations to reduce environmental damage	“
“	Importance of 'legislation, norms, regulations, standards and taxation as a barrier to innovative success	“
Canada (1993)	Government standards or regulations as a factor of particular significance as an impediment to innovation	Yes or no
“	Importance of factors in the firms general development strategy: 1. Using existing materials more efficiently 2. Reducing energy costs	five point scale from not important to crucial
“	Effects of the firm's most economically important innovation: 1. Reduced energy requirements 2. Reduced capital requirements 3. Reduced material requirements	Yes or no
MERIT-PACE (1993)	Importance of environmental regulations as an obstacle to the ability of the firm to profit from innovation	five-point scale ranging from not important to extremely important
CIS - 2 (1997)	Importance to the firm's innovative objectives of: 1. Reducing materials consumption 2. Reducing energy consumption 3. Reducing environmental damage	Not relevant category plus an importance scale of 1 to 3

The survey results indicate that firms are increasingly integrating environmental concerns in their activities. For example, three-quarters of the companies reported an increase in environment-related R&D expenditures, with over a quarter claiming more than a 25% increase, while 36% claimed that they had made a large change towards making 'personnel motivation and training' more environmentally-friendly. The problem with these conclusions is that they only apply to a small self-selected group of firms with a proven interest in environmental issues, as shown by their interest in ETIS. This highlights the need for an environmental survey based on an unbiased sample of firms.

Table 3: Summary of questions in the environmental innovation survey by Green et al

Main Question	Response categories
What factors prompted your company to develop environmentally-friendly new products/processes (or redesign existing products/processes)	Regulations Market factors Inputs (cost savings, new technologies) External pressures (environmental campaigns) Internal pressures (company policy)
To what extent during the last five years has your company made the following 'environmentally-friendly'	Products Production processes Distribution & transport Supplier policy personal motivation general operations
Estimate the change in resources (staff and money) to considering and tackling the environmental aspects of your products and processes	Five categories: decrease, about the same, up to 10% increase, 10-25% increase, over 25% increase
Specify a product and a process innovation undertaken in response to green pressures.	Is this a modification to an existing technology or a major change in technology? Resources required to develop these two innovations: expenditures, skills, collaboration, technical, and investment

Literature-based environmental innovation survey

A second survey of environmental innovation, by Malaman (1996), uses the Literature-Based Innovation Output (LBIO) method (Coombs *et al*, 1996; Kleinknecht *et al*, 1993). The study selects environmental innovations developed by Italian companies between 1970 and 1995. A database of 192 innovations from 168 companies was constructed from diverse information sources: entry forms for environmental awards, surveys of successful environmental innovations, projects that were submitted to a subsidy scheme for environmental innovations, research projects by Italian companies for international technological cooperation programmes (EC and Eureka), articles in the most important trade journals, and contacts with major industrial associations. Information on each innovation was obtained from published sources and from brief interviews with company representatives.

The innovations were classified into seven categories: cleaner products (28.6%), energy-saving technologies (8.3%), cleaner production processes (25.5%), recovery and recycling technologies (23.4%), end-of-pipe technologies (3.6%), products which modify production processes (8.3%), and environmental diagnostic and monitoring (1.0%). The development stage for each innovation was also assessed, using four stages: R&D, prototype, first application, or in the stage

of maturity. The most mature technologies are recovery and recycling technologies, end-of-pipe technologies and energy-saving technologies with 62.2%, 57.1% and 50.0% being in the mature stage. The differences in development reflect the different stages in environmental policy: in the mid seventies and early eighties (when prices for energy were soaring) the orientation was on energy saving, in the 1980s on pollution, in the late eighties and nineties on prevention, and more recently on product innovation.⁹

The study finds that most technologies are based on available knowledge, with relatively short development times (86.7% of the innovations had a development time of less than 5 years). Links with company strategies are broadly explored, by making a distinction between defensive and pro-active strategies¹⁰. The study also inquired into the pro-active nature of companies with respect to environmental issues. Finally, the study found that product and process innovations are quite often linked, with production process changes leading to cleaner products, input substitution and energy savings, and recovery and recycling. There also exist cross-media synergetic effects: 26% of the innovations led to benefits in multiple environmental media. Most process innovations (55%) led to a reduction in production costs, which suggests that offsets are relatively frequent.

The variety of interesting results from this study stress the usefulness of a LBIO approach, although it is not pursued further in this report. The main disadvantage of the LBIO method concerns the selection of innovations. This was probably biased towards the most successful environmental innovations and towards the most environmentally active firms. This is suggested by the finding that 41.8% of the Italian firms in the database have adopted a proactive environmental strategy. This is a very high figure that is highly unlikely to reflect average conditions in Italy. The figure is not representative for Italian industry since the firms included in the survey are the most environmentally innovative.

⁹ There also has been a development of the environmental units inside large industrial corporations. Groenewegen and Vergragt (1991) distinguish three overlapping phases. Before 1980, these units were small and their activities were mainly restricted to reaction on government regulation. Typically, their responsibility was regulatory compliance. Between 1984 and 1988 there was an increase in environmental care systems, which includes training, education, etc., at all levels in the organisation. Since the late 1980s, some large firms are thinking increasingly about environmental issues in a strategic way, i.e., in terms of threats and opportunities to the business, and to follow a proactive and preventive course.

¹⁰ Large companies in the chemical industry are found to be the most pro-active. One explanation for this are that chemical companies more than any other industry have been subject to environmental pressures, they also have the knowledge, capabilities and resources to deal with environmental problems.

Sector or technology specific environmental innovation surveys

Another option for environmental innovation surveys is to focus on a specific industrial sector or on the adoption of a defined set of environmental technologies. An example is a 1996 Statistics Canada survey of the use of biotechnology (Arundel, 1997). The survey asks all firms with over 3.5 million US in annual sales and in 17 industrial sectors if they currently use, or plan to use, one of five carefully-defined environmental biotechnologies. Users of one or more of these technologies are then asked a series of questions on investment, their reasons to adopt the technology, difficulties with implementation, results from their use, and the principal internal and external sources of information to assist the adoption of environmental biotechnologies.

IMPLICATIONS FOR ENVIRONMENTAL INNOVATION INDICATORS

Two broad classes of environmental indicators need to be developed. The first class consists of indicators that are unique to environmental innovation. The second class consists of indicators that are similar to those proposed in the Oslo Manual and used by the CIS, but which need to be adjusted for environmental innovation. An example is questions on information sources.

The next section briefly summarises the types of indicators that are needed. Some of the information can only be acquired through a direct question, for example on the types of environmental innovation undertaken by the firm. Other results can be obtained indirectly by analysing different types of questions. For example, the environmental strategy of a firm can partly be estimated on the basis of its answers to questions on the organisation of environmental innovation and on the types of innovation.

Some types of answers are, in fact, best obtained indirectly. This is because environmental innovation and pro-environment policies are often seen as ‘good’ whereas an anti-environment policy would be seen as ‘bad’. This means that firms could give biased responses that overestimate the amount of effort that they actually expend on environmental innovation. This is a problem that requires careful attention in the design of environmental innovation surveys.

Areas where environmental indicators are needed

Type of environmental innovation: Although general indicators on environmental innovation can be of value, a fundamental need is for indicators of the different types of environmental innovation. The taxonomy given in the Introduction can be used for this purpose. This taxonomy

also provides information on the firm's activities in developing product versus process innovations. Another useful question is to ask if the firm has plans to phase out environmentally unfriendly products and processes.

The purpose of environmental innovation is closely related to indicators on the type of environmental innovation. The purpose ranges from pollution reduction, energy saving, waste reduction (during production, transport, point of use), substitution of depletable resources and harmful substances, improved durability, recyclability, and so on. It is unclear whether or not a detailed break-down on the purpose of environmental innovation is necessary, and if it is obtained, if it should be gathered for each innovation separately or for all environmental innovations together.

Another question on the type of innovation is whether or not it is large-scale or incremental. Empirical research has shown that incremental improvements are an important source of cost reductions and product improvement (Enos, 1962). Yet, a focus on incremental innovation could lead to limited environmental gains. Large-scale innovations, either through the replacement of an entire production process or the development of a new product, provide greater options for marked improvements in environmental sustainability. The problem is how to measure incremental versus radical innovation, since these concepts vary by sector. The nature of a 'radical' innovation might not be apparent for some time. One possible approach is to obtain information on the cost of the innovation, on R&D spending, and on the sources of information. This will provide some insight into the types of innovation underway. In addition, it would be useful to have measures of the processes that lead to radical responses to environmental challenges. These could include the role played by government technology development programmes, current and future regulation, and visions of environmental sustainability.

Effect of government policies: Government regulation and covenants can have a direct effect on firm's innovation policies. Other possible influences include government policies such as R&D subsidies, technology adoption subsidies, technical assistance schemes, or procurement policies. Surprisingly, we know very little about the effect of these policies on environmental innovation or if firms find these policies to be effective incentives.

Internal organisational structures: Firms can be asked if they have adopted various organisational innovations to support environmental innovation. These include environmental

mission statements and long-term goals for emissions reductions, energy use, and environmental product improvements, Life Cycle Analyses (LCAs), environmental audits, and eco-design principles, collaboration with suppliers and users over environmental issues, contacts with public authorities, and the inclusion of environmentalists and citizens in the development of firm policy. Are such tools viewed as useful for identifying and achieving environmental improvements? How do firms determine which solution is best from an environmental point of view - do they use LCA or some other assessment method, make use of the company's own environmental knowledge base and information system, or use BAT guidance notes and lists for industry-specific processes?

Environmental strategies and motivations: Indicators of the organisational and strategic aspects of environmental R&D and management could help to identify the conditions that favour environmental innovation and help identify the circumstances in which environmental management operates as a self-propelling force. Many of the questions on strategic innovation can be formulated as innovation goals. These include to comply with current regulations, to pre-empt possible future regulations, social responsibility, and to capture a market for a new product. This type of information will provide useful data on the firm's motivations for environmental innovation. From a policy perspective, two important questions concern the main drivers for environmental innovation. Is it in response to regulation or to the firm's own innovation goals? Are the beneficial environmental effects deliberate or fortuitous? The results to many of these questions, including those on environmental organisation, will also be of interest to responding firms. They will be able to compare their own behaviour to that of other companies in the same sector.

The types of questions used to study strategies and motivations should also be useful for testing the continuum model of Green et al. (1994) or Steger's simpler version, both described above. This requires indirect analyses of environmental innovation indicators, since direct questions could lead to biased results.

Offsets: Indicators for cost offsets from environmental innovation are required to determine the usefulness of offsets as an incentive for environmental innovation.

Information sources: The development of effective public policies to stimulate environmental innovation requires information on the types of information sources that are most useful for these

purposes. For instance, how useful are universities, public laboratories, government bodies, sector organisations, and environmental transfer centres as a source of information for environmental innovation? And what kind of knowledge is transferred: knowledge about environmental effects, requirements, or solutions to environmental problems? One goal is to identify critical gaps in the knowledge infrastructure, while another is to identify which knowledge sources are most useful.

Collaboration: chain managements, product stewardships

Appropriability conditions: Environmental innovations can be developed by a firm for use in its own production processes only, by a firm who both uses the innovation and sells it to another firm, and by firms that only develop or supply environmental innovations to other firms. Of greatest interest here is the frequency with which user-developers keep the innovation secret or license it to other firms. The goal for policy is to encourage knowledge sharing.

ENVIRONMENTAL INNOVATION QUESTION MODULES

The sample environmental questionnaire that is provided below is four pages in length and never uses the term ‘innovation’. The first two pages consist of questions which should be answered by all firms, whether or not they introduce or develop environmental innovations, while the last two pages include questions that concern two specific, user-defined environmental innovations. The questionnaire is designed for use by firms of all sizes and in all manufacturing sectors.

To be successful, the questionnaire requires a slightly more complex sampling design. The last two pages consist of two sets of questions on two of the following six types of environmental innovation:

1. End-of-pipe pollution control technology
2. Waste management
3. Clean process-integrated technology
4. Recycling
5. Clean products.
6. Clean-up technology

Each firm will receive the first two pages plus a question module on two or three of the six technology options. The latter will be assigned randomly. For example, firm A could receive a question module on technologies 1 and 3, Firm B on 5 and 6, Firm C on 1 and 4, etc. There are two reasons for using this type of sample design. First, it will reduce the length of the questionnaire while still gathering technology-specific information. Second, firm respondents could become very, very bored with filling out the same basic form for up to six different technologies. This could substantially reduce the quality of the responses for the fourth, fifth, and sixth technologies.

The sample questionnaire included below only includes two technology modules: for process integrated technology and for clean products. It is a relatively simple task to adjust these modules for each of the other four technologies.

Sample Environmental Technology Questionnaire

General information on your firm

1.1 Please briefly describe your firm's main industrial or commercial activity. Include examples of your main products, if applicable:

1.2 How many employees did your firm have (full time equivalents) in 199X?

1.3 What was your firm's sales turnover (in national currency units) in 199X?

1.4 What percentage of your firm's turnover is from exports to countries *outside* of the EU?

☐ 0 - 10% ☐ 10% - 20% ☐ 20% - 30% ☐ 30% - 40% ☐ > 40%

2. Does your firm have any of the following:

- | | | |
|--|-----------------------------|------------------------------|
| 1. Environmental training programmes for production staff | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 2. Published mission statement in support of environmental goals | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 3. Product design programmes that incorporate environmental goals | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 4. Certified environmental audit (ISO 14000, BS7750, BMAS) | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 8. Designated management team responsible for environmental issues | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 6. Product life cycle analysis programme | <input type="checkbox"/> No | <input type="checkbox"/> Yes |
| 8. System to regularly monitor changes to environmental regulation | <input type="checkbox"/> No | <input type="checkbox"/> Yes |

3. How serious are each of the following environmental problems in your firm's sector of activity? (Please circle the appropriate response)

1 = not a problem..... a serious problem = 5

- | | | | | | |
|---|---|---|---|---|---|
| 1. Water pollution | 1 | 2 | 3 | 4 | 5 |
| 2. Soil pollution | 1 | 2 | 3 | 4 | 5 |
| 3. Air pollution | 1 | 2 | 3 | 4 | 5 |
| 4. Waste accumulation after the use of the product or service | 1 | 2 | 3 | 4 | 5 |
| 8. Excessive noise production | 1 | 2 | 3 | 4 | 5 |
| 6. Offensive odour production | 1 | 2 | 3 | 4 | 5 |

4. In the last three years, has your firm implemented or conducted research on the following six types of environmental technology?

	Implemented a technology of this type?		Conducted research such as R&D or engineering studies?	
4.1 <i>Pollution control technology</i> to prevent the release of pollutants into the soil, air or water	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes
4.2 <i>Waste treatment</i> and disposal systems	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes
4.3 <i>Clean technology</i> , or process-integrated production technology to reduce the production of waste	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes
4.4 <i>Recycling technology</i> to re-use materials	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes
4.5 <i>Cleaner products</i> that have a lower environmental impact during their normal use	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes
4.6 <i>Clean-up technology</i> to reduce pollutant levels in soil or water	<input type="checkbox"/> No	<input type="checkbox"/> Yes	<input type="checkbox"/> No	<input type="checkbox"/> Yes

5. Does your firm conduct R&D?

☐ No

☐ Yes, occasionally

☐ Yes, continuously

If yes, how much did your firm spend on R&D in 199X?

What percent of this budget was spent on environmental technologies?

..... %

6. What are the principal information sources used by your firm to learn about environmental problems and their technical solutions? (Please check all that apply)

	Problems	Technical Solutions
A. Your firm's R&D department	<input type="checkbox"/>	<input type="checkbox"/>
B. Your firm's production department	<input type="checkbox"/>	<input type="checkbox"/>
C. An affiliated firm (parent firm, etc)	<input type="checkbox"/>	<input type="checkbox"/>
D. Universities	<input type="checkbox"/>	<input type="checkbox"/>
E. Technical institutes	<input type="checkbox"/>	<input type="checkbox"/>
F. Technology transfer centres	<input type="checkbox"/>	<input type="checkbox"/>
G. Scientific journals or trade publications	<input type="checkbox"/>	<input type="checkbox"/>
H. Government Environmental Ministry	<input type="checkbox"/>	<input type="checkbox"/>
I. Equipment suppliers	<input type="checkbox"/>	<input type="checkbox"/>

Which was the most important source for learning about environmental problems?

Which was the most important source for technical solutions?

The next two question groups ask more detailed questions about two of the environmental technologies listed above in question 4.

7. In the last three years, did your firm introduce *process-integrated changes* to your production technology to reduce the generation of pollutants and waste material?

☐ No ☐ Yes ☐ Don't know

If Yes, please answer the following questions, limiting your responses to the technology that required the **largest initial investment** by your firm. If no, go to question 8.

7.1 What was the approximate cost of the capital investment for this technology? < 100,000 ☐ 100,001 - 1 m ☐ > 1 million ☐

7.2 By what percentage has the adoption of this technology affected operating costs? Increased% ☐ No noticeable change
Decreased%

7.3 Which of the following contributed to the development of this technology?

Outside supplier or manufacturers of the technology	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Your firm's production department	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Your firm's R&D department	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Other	<input type="checkbox"/> No	<input type="checkbox"/> Yes

7.4 Is this technology:

Patented by your firm (or a patent application been made) ?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Patented by another firm (or a patent application been made)?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Licensed to your firm?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Licensed by your firm to another firm?	<input type="checkbox"/> No	<input type="checkbox"/> Yes

7.5 Has your firm received any of the following forms of government assistance to introduce this technology?

R&D or other development subsidies	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Technology adoption subsidies	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Other	<input type="checkbox"/> No	<input type="checkbox"/> Yes

7.6 How important were each of the following reasons for your firm's decision to introduce this technology? (Please circle the appropriate response)

1 = not important, 5 = extremely important

Customer or consumer demand	1	2	3	4	5
Shareholder or investor demand	1	2	3	4	5
Comply with existing environmental regulations	1	2	3	4	5
Comply with expected <i>future</i> environmental regulations	1	2	3	4	5
Reduce production costs	1	2	3	4	5
Employee safety	1	2	3	4	5
Pressure from environmental or citizen groups	1	2	3	4	5

8. In the last three years, did your firm introduce any *cleaner products* that have a lower environmental impact during their normal use?

☐ No ☐ Yes ☐ Don't know

If Yes, please answer the following questions, limiting your responses to the cleaner product with **the highest sales**. If no, go to question 9.

8.1 What was the approximate cost of the initial investment to develop or improve this product? ☐ < 100,000 ☐ 100,001 - 1 m ☐ > 1 million ☐

8.2 Which of the following contributed to the development of this product?

Outside supplier or manufacturers of the technology	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Your firm's production department	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Your firm's R&D department	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Other	<input type="checkbox"/> No	<input type="checkbox"/> Yes

8.3 Are the cleaner technical features of this product:

Patented by your firm (or a patent application been made) ?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Patented by another firm (or a patent application been made)?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Licensed to your firm?	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Licensed by your firm to another firm?	<input type="checkbox"/> No	<input type="checkbox"/> Yes

8.4 Has your firm received any government assistance to introduce this product?

R&D or other development subsidies	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Technology adoption subsidies	<input type="checkbox"/> No	<input type="checkbox"/> Yes
Other	<input type="checkbox"/> No	<input type="checkbox"/> Yes

8.5 How important were each of the following reasons for your firm's decision to introduce this product? (Please circle the appropriate response)

1 = not important, 5 = extremely important

Customer or consumer demand	1	2	3	4	5
Shareholder or investor demand	1	2	3	4	5
Comply with existing environmental regulations	1	2	3	4	5
Comply with expected <i>future</i> environmental regulations	1	2	3	4	5
Reduce production costs	1	2	3	4	5
Employee safety	1	2	3	4	5
Pressure from environmental or citizen groups	1	2	3	4	5

9. If you would you like a copy of the report to be based on the results of this survey, please provide your name and address in the space below:

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